EE 527 MICROFABRICATION

Lecture 24

Tai-Chang Chen
University of Washington

UNIVERSITY OF WASHINGTON

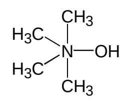
EDP ETCHING OF SILICON - 1

- Ethylene Diamine Pyrocatechol
- Anisotropy: (100):(111) ~ 35:1
- EDP is very corrosive, very carcinogenic, and never allowed near mainstream electronic microfabrication.
- Typical etch rates for (100) silicon:

70°C	14 μm/hr
80°C	20 μm/hr
90°C	30 μm/hr = 0.5 μm/min
97°C	36 μm/hr

TMAH ETCHING OF SILICON

- Tetra Methyl Ammonium Hydroxide
- MOS/CMOS compatible:
  - No alkali metals {Li, Na, K, …}.
  - TMAH is used in many positive photoresist developers.
  - Does not significantly etch SiO_2 or Al! (Bond wire safe!)
- Anisotropy: (100):(111) ~ 10:1 to 35:1
- Typical recipe:
  - 250 mL TMAH (25% from Aldrich)
  - 375 mL H_2O
  - 22 g Si dust dissolved into solution
  - Use at 90°C
  - Gives about 1 μm/min etch rate



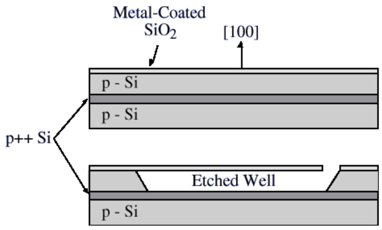
tetramethyl ammonium hydroxide
(TMAH)

ANISOTROPIC ETCH STOP LAYERS - 1

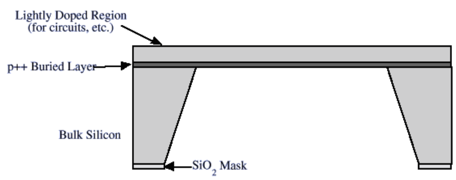
- Controlling the absolute depth of an etch is often difficult, particularly if the etch is going most of the way through a wafer.
- Etch stop layers can be used to drastically slow the etch rate, providing a stopping point of high absolute accuracy.
- Boron doping is most commonly used for silicon etching.
- Requirements for specific etches:
  - HNA etch actually speeds up for heavier doping
  - KOH etch rate reduces by 20× for boron doping > 10^{20} cm^{-3}
  - NaOH etch rate reduces by 10× for boron doping > 3×10^{20} cm^{-3}
  - EDP etch rate reduces by 50× for boron doping > 7×10^{19} cm^{-3}
  - TMAH etch rate reduces by 10× for boron doping > 10^{20} cm^{-3}

DOPANT ETCH STOPS

- Many anisotropic etchants slow down markedly at high boron concentrations (» 10^{20} cm^{-3}).
- Can diffuse or grow boron-containing epitaxial silicon.



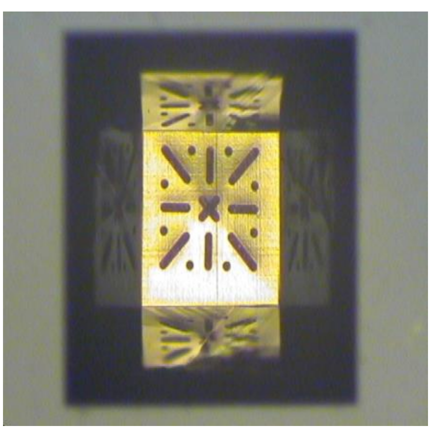
Cantilever (Petersen '82)

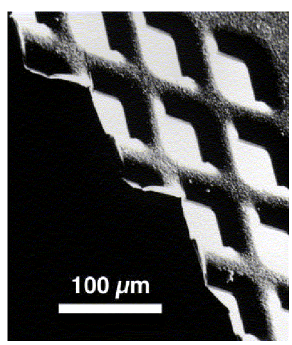


Membrane formation

Figures: G. Kovacs 1997

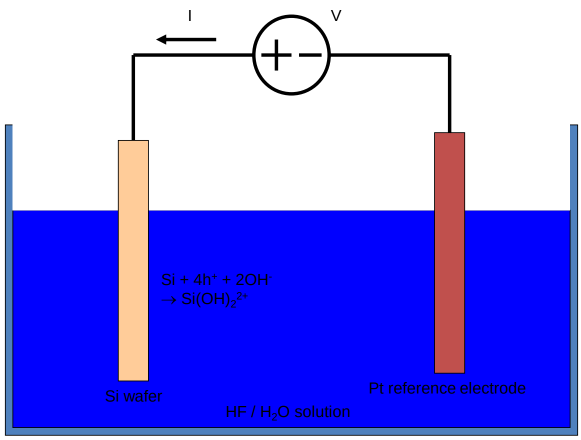
BORON P++ ETCH STOPS





Figures: G. Kovacs 1997

ELECTROCHEMICAL ETCH EFFECTS - 1

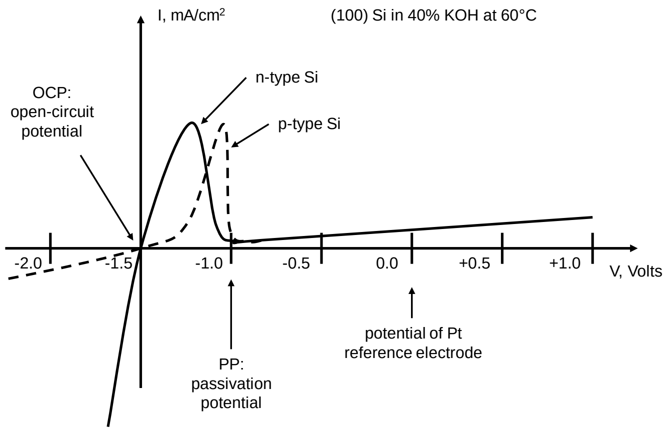


The supply of holes (h+) to oxidize Si is a common element of all Si etches. Because of this, Si etches can be electrically controlled.

ELECTROCHEMICAL ETCH EFFECTS - 2

- HF normally etches SiO_2 and terminates on Si.
- By biasing the Si positively, holes can be injected by an external circuit which will oxidize the Si and form hydroxides which the HF can then dissolve.
- This produces an excellent polishing etch that can be very well masked by LPCVD films of Si_3N_4.
- If the etching is performed in very concentrated HF, then the Si does not fully oxidize when etched, and porous silicon is formed, which appears brownish.
- Porous silicon has some unusual electroluminescent properties: It will glow bright orange under electron injection.

ELECTROCHEMICAL ETCH EFFECTS - 3

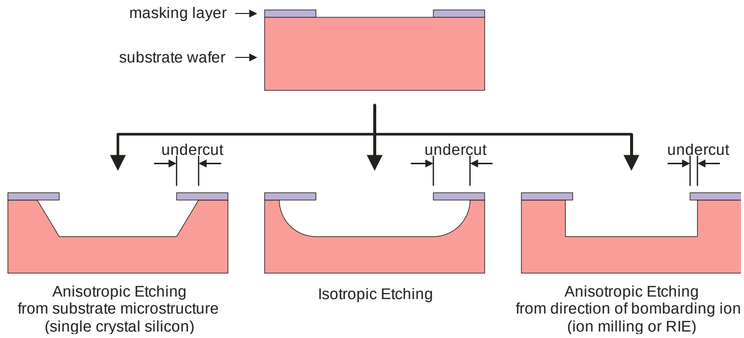


ELECTROCHEMICAL ETCH EFFECTS - 4

- The open circuit potential (OCP) is usually about −1.50 V, varying a bit with temperature and solution concentration.
- Increasing the wafer bias above the OCP will increase the etch rate by supplying holes which will oxidize the Si.
- Increasing the wafer bias further will reach the passivation potential (PP) where SiO_2 forms.
  - This passivates the surface and terminates the etch. The SiO_2 creates an insulating film which drastically reduces the current flow.

ETCHING ANISOTROPY

- Etch anisotropy determines the amount of masking layer undercut:



REASONS FOR DRY ETCHING

- Wet release of suspended structures can cause breakage and sticking due to surface tension of liquid pulling surfaces together upon removal.
- Dry etching is carried out at low pressures inside vacuum chambers, so particle contamination is greatly reduced.
- Dry etching is well suited for single wafer processing.
- Dry etching allows for precision end point control.

WET ETCHING V.S. DRY ETCHING (1)

- Wet Etching:
  - use liquid etchants.
  - mostly chemical processes.
  - simple, inexpensive, very selective.
- Plasma Etching/ Dry Etching:
  - use gas-phase etchants in a plasma.
  - combination of physical and chemical processes.
  - (combination of ionic and reactive chemical species)

DRY ETCHING OVERVIEW

- Dry Chemical etching
  - Chemical etching
- Physically sputtering (ion etching)
  - Sputter etch
- Combination of physical and chemical etching
  - Reactive ion etching (RIE)
  - Deep reactive ion etching (DRIE)
    - Bosch Process

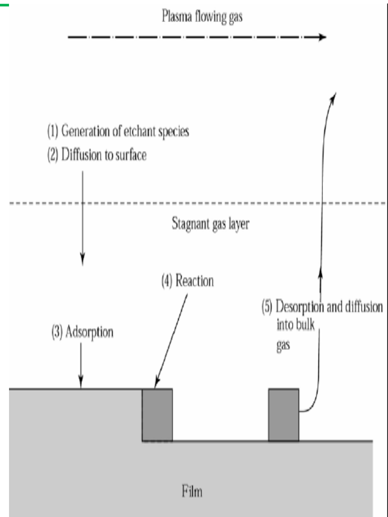
DRY ETCH

- Advantages
  - Controlled anisotropic etching of fine features
  - Controlled etch rate
  - Easier to automate
  - Smaller amount of hazardous chemicals
  - Etch chemically resistive chemicals
- Disadvantages
  - Expensive
  - Chemically not well know
  - Chemically less selective

ISOTROPIC DRY ETCHING (11.6)

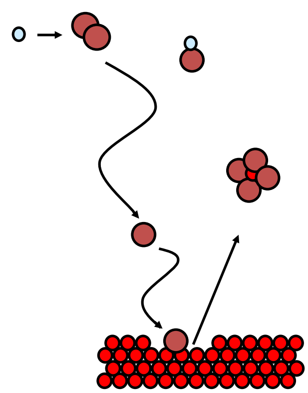
ETCH MECHANISMS

- Generation of etching species
- Diffusion to surfaces
  - the mechanics of getting to the surface can limit ***aspect ratio, undercuttig, uniformity***
- Adsorption
- Reaction
- Desorption
- Diffusion to bulk gas
  - can lead to non-uniform etching due to dilution of un-reacted etching species



DRY CHEMICAL ETCHING

- Relative high pressure process
- chemically reactive species
  - Diffuse to wafer surface
  - Adsorb onto surface
  - React with surface
  - Reaction by-products desorb and diffuse away
- Isotropic
- High selectivity
- Note: Gaseous by-products can be harmful!



XEF_2 STAGNANT GAS PHASE ETCHING

- Silicon is readily etched by noble gas halogens.
- XeF_2 is the most commonly used:
  - $2XeF_2 + Si \rightarrow 2Xe + SiF_4$.
  - XeF_2 is a solid at room temperature which can be sublimated by low pressure (exposure to vacuum).
  - Typically used at a pressure of 1-2 Torr to give Si etch rates of 1-3 µm/min.
  - Very high selectivity: virtually no etch rate for Al, SiO_2, Si_3N_4, and photoresist.
  - Leaves a very rough surface
  - Exothermic: ~1 W/cm^2 of heat produced.
  - Samples must be thoroughly dehydrated before etching.
  - $2XeF_2 + 2H_2O \rightarrow 2Xe + 4HF + 2O_2$. (HF etches SiO_2!)

XEF_2 ETCHING SYSTEM

- Refer to Hoffman, et al., MEMS 1995 Conference.

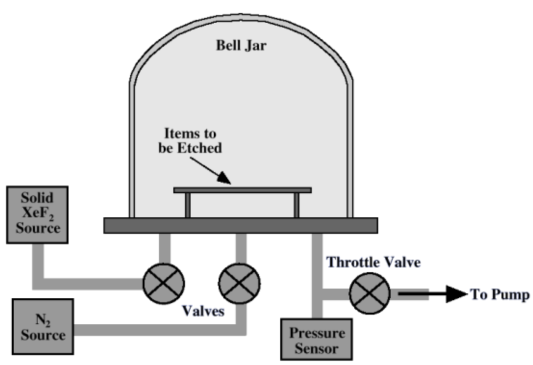
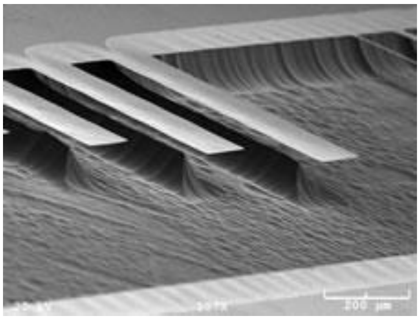


Figure from Kovacs, MMTSB, 1998.

COMMERCIAL XEF_2 ETCHING SYSTEM

- XACTIX model X4 system:



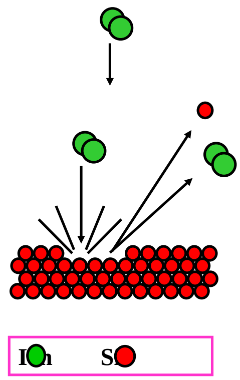
Aluminum cantilevers released using XeF_2 system. (XACTIX & Chad O'Neal, Louisianna Tech. Univ.)

PLASMA EXCITATION

- Because of their low density, most gas phase etching chemistries have rates that are too slow at room temperature.
- Increasing the rate requires exciting the reacting species to form radicals and giving these radicals kinetic energy.
- There exist several ways to achieve this:
  - Direct heating.
  - Electromagnetically coupled energy from an electrical discharge and used to create a plasma state.
- Advantages of plasmas:
  - Electrically controllable with high power efficiencies.
  - Creates free radicals through ionization.
  - Creates high kinetic particle energies without high substrate temperatures.
  - Performed in a vacuum chamber, giving good contamination control.

PHYSICAL ETCHING (SPUTTER)

- Low pressure, long mean free path
- Chemically inert ions (Ar)
  - Ions accelerated by plasma sheath potential towards wafer
  - Substrate atoms are dislodged during collisions (sandblasting)
    - Ion energy > Bonding energy
- Highly anisotropic
- Low selectivity
  - Etches all surfaces equally
- Mask needs 50% thicker than etch depth



ION MILLING SYSTEM

- Kaufmann source
  - Use e-beam to strike plasma
  - A magnetic field applied to increase ion density
- Drawback
  - Low etch rate
  - High ion bombardment damage
  - redeposition